# Recent Developments in LS-DYNA – I

John Hallquist

Livermore Software Technology Corporation, Livermore, USA

# New Developments in LS-DYNA®

## DYNAmore User Meeting

J.O. Hallquist

October 12-13, 2006

Livermore Software Technology Corporation

LSTC
Livermore Software
Technology Corp.

# Outline of talk

- Introduction
- New features in version 971 release 2
- New features in version 971 release 3
- EFG developments
- Implicit
- Conclusions

LSTC
Livermore Software
Technology Corp.

# LS-DYNA development

- We recognize that no single method is superior in all applications
- New developments and methodologies take time before gaining general acceptance and robustness
- Requests for developments from users are given the highest development priority
- Accuracy, speed, and scalability are the critical considerations for large scale simulations
- New releases must accept and run all input files from all previous releases without translation

# Development goals

- Combine multi-physics capabilities in a scalable code for solving highly nonlinear transient problems to enable the solution of coupled multi-physics and multi-stage problems in one run
  - Full 2D & 3D capabilities
  - Explicit Solver
  - Implicit Solver
  - Heat Transfer
  - ALE, EFG, SPH, particle methods
  - Navier-Stokes Fluids (version 980)
  - Radiation transport (version 980)
  - Electromagnetics (version 980)
  - Interfaces for users, i.e., elements, materials, loads, etc.
  - Interfaces with other software, Madymo, USA, etc.

## Development goals-implicit

- Springback for sheet metal stamping
- Static initialization of crash models
- Dynamic springback simulation after crash simulation
  - Reliable measurements between numerical and physical results can be more easily obtained
- An embedded linear capability to automatically solve for normal modes, attachment modes, and constraint modes
  - Include infinitesimal motions superimposed on rigid bodies for NVH and durability modeling
- Eigenvalue analysis to check the rigid body modes in the crash models
  - Identify inadvertent constraints

## Development of one code has advantages

- Huge cost savings relative to developing an array of software applications.
  - Explicit elements only need added stiffness matrix
  - Features needed for implicit applications are available for explicit
    - Double precision
    - 2nd order stress updates
  - Implicit MPP utilizes all prior efforts for explicit solver
  - Pre and post-processing software development supports one interface and common databases
  - QA is performed on one code.

# LSTC's vision

- In automotive, one model for crash, durability, NVH shared and maintained across analysis groups
- One scalable multi-physics code, LS-DYNA, to enable the complete modeling of crash including airbags, occupants, and fuel tank.
- Manufacturing simulation results from LS-DYNA used in crash, durability, and NVH modeling
- Explicit durability and NVH modeling go mainstream in MD Nastran
- No optional added cost LSTC developed features in LS-DYNA

LSTC Livermore Software Technology Corp.

# LSTC's vision

- LS-DYNA specific pre-processing, post-processing, LS-PrePost, and optimization, LS-OPT, with no added charges.
- Unrestricted open databases
- Focus on large distributed memory low-cost clusters running large simulations
- As processor costs decrease and cluster sizes increase, LS-DYNA software prices per processor will proportionally decrease to keep simulation costs affordable
- Optimization technology will automate engineering design calculations. LS-OPT is considered a critical enabling technology

LSTC Livermore Software Technology Corp.

## Current state of explicit

- Currently, typical large simulation models typically contain 1,000000 to 4,000,000 elements.
- FEA dummies are preferred over rigid body dummies in crash simulations
- 12-32 processors are used in runs that complete within 12-24 hours
- Calculations give digit-to-digit repeatability for a fixed domain decomposition.
- MPP version is recommended if more than 4 processors are used per run
- Model sizes continue to grow faster than Processor speed

LSTC Livermore Software Technology Corp.

## Near future for explicit

- Model sizes of 10,000,000 elements
- 128-512 processors in overnight runs
- Human dummy models, such as THUMS, will increase model sizes even further
- Honeycomb barriers will be modeled by shell elements
- Number of processors will increase 5-10 times
- Optimization software use in crash analysis will become widespread

LSTC Livermore Software Technology Corp.

# Final goal for explicit simulations

- Simulation results accepted in place of prototype testing
  - What is required?
    - Strict modeling guidelines for analysts, and a single comprehensive model for crash, NVH, Durability, etc.
    - Continued software improvements
      - Constitutive models
      - Contact
      - FSI with SPH, ALE, Particle methods
      - Sensors and control systems
      - Complete compatibility with NASTRAN
    - Manufacturing simulations (in LS-DYNA, Moldflow, etc.) providing the initial conditions for crash simulations

LSTC Livermore Software Technology Corp.

# Parallel computing

- In less than one decade from 1998-2006 the use of explicit codes has undergone a radical transformation
  - From 100% serial and SMP licensed CPU's for crash to 90% MPP with the remaining 10% of CPU's typically running smaller models on 1-8 processors
  - Today serial and SMP explicit codes are becoming obsolete and will eventually be phased out
- What about implicit?
  - More difficult to create an MPP version
  - Requires more expensive hardware so there is less customer pressure to create MPP versions
  - However, it is safe to predict that serial and SMP implicit solvers *used in large scale nonlinear simulations* will also become obsolete within the next 5 years.

LSTC Livermore Software Technology Corp.

## Scalability on large clusters

- IBM BlueGene/L computer is based on low cost PowerPC processors with modest clock speed, low power consumption, high speed network
- 2**16 (65000+) parallel processors
- Scalability of LS-DYNA on 1,048,576 element customer model run to completion:
  - 128 -Elapsed time 5 hours 27min. 437564 cycles
  - 256 -Elapsed time 2 hours 44min. 437564 cycles
  - 512 -Elapsed time 1 hour 27min. 437564 cycles
  - 1024 -Elapsed time 50min. 437564 cycles
  - 2048 -Elapsed time 32min. 437564 cycles

## Scalability on large clusters

- Cray XD1 with RapidArray interconnects AMD Dual Core Opteron 2.2 GHz
- 3 Car crash simulation run to completion (750K nodes)

Nodes x (processors/node) x (cores/processor)

| | | |
|---|---|---|
| 64 x 2 x 2 = 256 | 1696 sec | |
| 32 x 2 x 2 = 128 | 2416 | |
| 24 x 2 x 2 = 96 | 2981 | single core 2.2 GHz |
| 16 x 2 x 2 = 64 | 3846 | 32 x 2 x 1 = 64 4619 |
| 12 x 2 x 2 = 48 | 5226 | |
| 8 x 2 x 2 = 32 | 7591 | |
| 4 x 2 x 2 = 16 | 14078 | |
| 2 x 2 x 2 = 8 | 26230 | 4 x 2 x 1 = 8 24681 |
| 1 x 2 x 2 = 4 | 49460 | 2 x 2 x 1 = 4 47611 |

## Release of version 971_R2

- Version 971 was intended to be an update to version 970 to include parallel implicit
- Implementation of implicit parallel has taken years longer than planned
- Version 971_R1 was released during the 4th quarter of 2005
  - Multiple customers requested additional capabilities before switching from version 970
- Version 971_R2 now includes nearly all additional requested capabilities
- Manual will be published by August 2006 and will include new features in the R3 release.

LSTC Livermore Software Technology Corp.

## Version 971_R2 developments

LSTC Livermore Software Technology Corp.

# *Database_extent_binary

- New flag to output nodal mass scaling information into the D3PLOT database
  - EQ.1: Output incremental nodal mass
  - EQ.2: Output percentage increase in nodal mass
- In the past only the change in mass at the element level was available

# *Database_extent_binary

- New output options for metal forming applications
- For each contact interface a new flag is available to output:
  - peak pressure
  - surface energy density
- Allows segregating the energies generated on the upper and lower shell surfaces
- Data is remapped after each H-adaptive remesh.

## *Database_extent_binary

- For metalforming applications with thermal effects, there is a new option to output of thermal data to d3plot:
  - EQ.0: (default) output temperature
  - EQ.1: output temperature and flux
  - EQ.2: output temperature, flux, and shell lower and upper surface temperatures for the 12-node thermal shells

LSTC Livermore Software Technology Corp.

## *Database_nodout

- The size for the nodal history file NODOUT can be huge due to the need for have a small set of nodal output at a very high frequency
- Two NODOUT files can now be created:
  - NODOUT at a large output time interval
  - NODOUTHF at a small output time interval
    - For accelerometer nodes
- Nodes for high frequency output are flagged in *Database_history_node input

LSTC Livermore Software Technology Corp.

# *Database_matsum

- *CONTROL_OUTPUT flag to:
  - Output eroded internal and kinetic energy into the MATSUM file by part ID.
  - Output the kinetic energy from the added mass under part ID 0, which includes mass defined under:
    - *ELEMENT_MASS
    - Nonstructural mass distributions defined in *SECTION_SHELL
    - *ELEMENT_MASS_PART.

# Labels and Numeric ID's

- 8-character alphanumeric labels can now be used for SECID, MID, EOSID, HGID, and TMID throughout the keyword input

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PID | SECID | MID | EOSID | HGID | GRAV | ADPOPT | TMID |
| Type | I | I/A | I/A | I/A | I/A | I | I | I/A |
| Default | none | none | none | 0 | 0 | 0 | 0 | 0 |

# *Element_mass_part

- Defines the total additional non-structural mass to be distributed by an area weighted distribution to all nodes of a given part ID.
- Applies to all part ID's defined by shell elements.
- Provides an alternative method to giving the non-structural mass per unit area in the section definition.

LSTC Livermore Software Technology Corp.

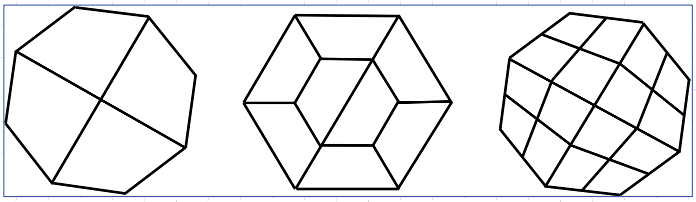
# *Define_hex_spotweld_assembly

- Development motivated by spotweld studies at Honda USA which showed the superiority of using multiple solid elements for each weld.
- Define a list of hexahedral solid elements clusters that make up a single spot weld for computing the force and moment resultants that are written into the SWFORC output file and also used for failure predictions.
- A maximum of a 16 element cluster may be used to define single spot weld.
- This table is generated automatically when beam elements are converted to solid elements.

LSTC Livermore Software Technology Corp.

# *Define_hex_spotweld_assembly

- Sample four, eight, and sixteen element spot weld clusters comprised of solid hexahedron elements. {Courtesy Honda, USA}



LSTC Livermore Software Technology Corp.

# *Control_spotweld_beam

- New option to replace each spot weld beam element with a cluster of solid elements of 1, 4, or 8 solid elements.
- For 4 or 8 solid elements, a table is automatically generated to output the force and moment resultants into the SWFORC using the ID of the beam element which is replaced by the solid elements and for failure predictions
- The beam elements are automatically deleted from the calculation, and the section and material data is automatically changed to be used with solid element or solid element cluster

LSTC Livermore Software Technology Corp.

# Spotweld failure

- The recent use of high strength steels has motivated new developments for predicting spot weld failure
  - With mild steels the spot weld failure mode is tear out
  - With high strength steels the failure mode is either tear out or spot weld fracture
    - Depends on the ratio of shear versus axial loading
- Two failure models are now available: the first for beam elements, developed by Toyota; and the second for single solid elements, developed by DaimlerChrysler

LSTC Livermore Software Technology Corp.

# Spotweld new development

- New constitutive model: *MAT_SPOTWELD_ DAIMLERCHRYSLER
  - The DAIMLERCHRYSLER failure model assumes that failure of the spot weld depends on properties of the welded materials so this keyword allows shell material failure data to be input for the connection
  - References connection ID which is defined via:
    - *DEFINE_CONNECTION_PROPERTIES
  - Implemented for single solid elements
  - Includes damage and rate effects
  - Much easier to use and more general than the previous option: *DEFINE_SPOTWELD_FAILURE_RESULTANTS

LSTC Livermore Software Technology Corp.

# Spotweld new development

- *DEFINE_CONNECTION_PROPERTIES
  - References material ID's used in part definitions and defines a failure criteria for the material ID's.
  - One or more connection ID's can be defined
  - A 3-parameter failure criteria is used

$$f = \left(\frac{\sigma_n}{\sigma_n^F(\dot{\varepsilon})}\right)^{m_n} + \left(\frac{\sigma_b}{\sigma_b^F(\dot{\varepsilon})}\right)^{m_b} + \left(\frac{\tau}{\tau^F(\dot{\varepsilon})}\right)^{m_\tau} - 1$$

$$\sigma_n = \frac{N_{rr}}{A} \qquad \sigma_b = \frac{\sqrt{M_{rs}^2 + M_{rt}^2}}{Z} \qquad \tau = \frac{M_{rr}}{2Z} + \frac{\sqrt{N_{rs}^2 + N_{rt}^2}}{A} \qquad Z = \pi\frac{d^3}{32}$$

LSTC Livermore Software Technology Corp.

# Sensors for Automotive Safety

- There are over 110 sensors in the average vehicle today, e.g.,
  - Pressure sensor for brake, tire
  - Force and torque sensor for suspension
  - Acceleration, velocity and displacement sensor for suspension, vehicle and occupant
  - Occupant classification sensor for restraint system
  - Strain gauge for steel and seat

LSTC Livermore Software Technology Corp.

# *Sensor

- *SENSOR_DEFINE defines a physical sensor. The output signal is the numerical value of a physical sensor.
- *SENSOR_SWITCH compares the sensor signal with a given criterion. The output signal is the logical result, true or false.
- *SENSOR_CONTROL controls a function, airbag, contact,…, based on the logical result of a set of SENSOR_SWITCH. Multiple status switch is possible.

LSTC Livermore Software Technology Corp.

# *Contact_force_transducer

- Scalability of LS-DYNA to hundred's of processors is limited by contact
  - Scalability for 1-2 contact definitions covering the entire vehicle is excellent
  - Scalability for 300+ contact definitions diminishes significantly as the number of processors increase
    - 300 contact definitions are used to obtain detailed reaction force information.

LSTC Livermore Software Technology Corp.

# *Contact_force_transducer

- Force transducers measure contact forces within a vehicle by accumulating all forces acting on a segment set during contact.
  - Problem is that these transducers cannot separate the forces in two-sided contact
- In version 971_R2 a master surface is also accepted such that the reaction force is accumulated by the interactions of the slave and master surfaces
  - It is now possible to move to fewer contact interfaces and improve scalability.

LSTC Livermore Software Technology Corp.

# Smooth contact with CAD

- Contact with CAD surface (IGES and VDA formats) has been available in LS-DYNA for ~15 years but rarely used
  - Advantages:
    - Smooth surface eliminate sudden changes in the surface normal vectors
      - Contact force calculations and work piece stresses are more accurate
      - Springback predictions are more accurate
  - Disadvantages:
    - Contact search and treatment is time-consuming
    - Not robust due to poor quality CAD data

LSTC Livermore Software Technology Corp.

# Smooth contact with FEA

- A smooth curve-fitted surface represents the contact surface
- Eliminates sudden changes in the surface normal across the element
- Provides a more accurate representation of the physical surface.
- Reduces the contact noise and produces a smoother result with less mesh sensitivity
  - More accurate residual stresses provide for springback results which are comparable to CAD springback results
- Less sensitivity to contact penalty parameters
- Implemented for MPI.

LSTC Livermore Software Technology Corp.

# MPP smooth contact

*CONTACT_NODES_TO_SURFACE_SMOOTH
*CONTACT_ONE_WAY_SURFACE_TO_SURFACE_SMOOTH
*CONTACT_SURFACE_TO_SURFACE_SMOOTH

*CONTACT_AUTOMATIC_NODES_TO_SURFACE_SMOOTH
*CONTACT_AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE_SMOOTH
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_SMOOTH

*CONTACT_AUTOMATIC_SINGLE_SURFACE_SMOOTH

*CONTACT_FORMING_ONE_WAY_SURFACE_TO_SURFACE_SMOOTH
*CONTACT_FORMING_NODES_TO_SURFACE_SMOOTH

LSTC Livermore Software Technology Corp.

# *Mat_samp-1

- A semi-analytical model for the simulation of isotropic ductile thermoplastic polymers
- Developed at Mercedes by Paul DuBois, Stefan Kolling, Markus Feucht, & André Haufe
- Implemented in version 971 for explicit option
- Features
  - Implemented for solid and shell elements
  - Fully tabulated input data
  - Most general quadratic isotropic yield surface formulation, can fit 3 experiments exactly and 4 approximately (least squares)
  - Damage model accurately simulates unloading response

# *Contact_...._thermal_friction

1. Friction coefficients a function of temperature
2. Contact conductance a function of pressure

Mechanical friction coefficients vs. temperature

Static → $\mu_s = \mu_s$ * lcfs(T)

Dynamic→ $\mu_d = \mu_d$ * lcfd(T)

lcfs lcfd formula a b c d

| Formula | | |
|---|---|---|
| 1 | $h(P)$ is defined by load curve "a" | Tabulated data |
| 2 | $h(P) = a + bP + cP^2 dP^3$ | Polynomial curve fit |
| 3 | $h(P) = \frac{\pi k_{gas}}{4\lambda}\left[1. + 85\left(\frac{P}{\sigma}\right)^{0.8}\right] = \frac{a}{b}\left[1. + 85\left(\frac{P}{c}\right)^{0.8}\right]$ | I.T. Shvets, "Contact Heat Transfer between Plane Metal Surfaces", Int. Chem. Eng., Vol4, No. 4, p621, 1964. |
| 4 | $h(P) = a\left[1 - \exp\left(-b\frac{P}{c}\right)\right]^d$ | Li & Sellers, Proc. Of 2nd Int. Conf. Modeling of Metals Rolling Processes, The Institute of Materials, London, 1996. |